NEW TECHNIQUES FOR SIMULATOR INSTRUCTION

UTP-2 WORKSHOP PROCEEDINGS

JUNE 1992

VICTORIA, BRITISH COLUMBIA, CANADA

Report Documentation Page		*Form Approved* *OMB No. 0704-0188*

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **JUN 1992**	2. REPORT TYPE **Proceedings**	3. DATES COVERED **01-01-1991 to 15-06-1992**
4. TITLE AND SUBTITLE **Performance diagnosis for air combat training**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER **62205F**
6. AUTHOR(S) **Wayne Waag**		5d. PROJECT NUMBER **1123**
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Armstrong Laboratory,Aircrew Trainng Research Division,6030 South Kent Street,Mesa,AZ,85212-6061**		8. PERFORMING ORGANIZATION REPORT NUMBER **; AFRL-RH-AZ-PR-1992-0001**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) **Air Force Research Laboratory/RHA, Warfighter Readiness Research Division, 6030 South Kent Street, Mesa, AZ, 85212-6061**		10. SPONSOR/MONITOR'S ACRONYM(S) **AFRL; AFRL/RHA**
		11. SPONSOR/MONITOR'S REPORT NUMBER(S) **AFRL-RH-AZ-PR-1992-0001**

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
In Proceedings of the UTP-2 Workshop on New Techniques for Simulator Instruction, held June 1992, in Victoria, British Columbia, Canada, pp 23-38

14. ABSTRACT
This paper summarizes research at the Aircrew Training Research Division of the Armstrong Laboratory that is attempting to enhance air combat training through the development of performance diagnosis capabilities. Three systems are described: the Observing System for Critique, Advice, and Review (OSCAR), a system which provides performance diagnosis capabilities for air intercept training; the Air Combat Maneuvering Performance Measurement System (ACM PMS), a system that provides real-time measures of positional advantage and energy management for air combat engagements flown in either a simulation or range environment; and the Intelligent System for Air-to-Air Combat (SAAC) which provides diagnostic feedback capabilities for air combat maneuvering engagements.

15. SUBJECT TERMS
Air combat training; Performance diagnosis capabilities; Observing System for Critique, Advice, and Review (OSCAR); Air intercept training; Air Combat Maneuvering Performance Measurement System (ACM PMS); Real-time measures; Energy management; Air combat engagements; Simulation environment; Range environment; Intelligent System for Air-to-Air Combat (ISAAC); Diagnostic feedback capabilities

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Public Release**	**17**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

PERFORMANCE DIAGNOSIS FOR AIR COMBAT TRAINING

Wayne L. Waag
Armstrong Laboratory
United States Air Force
Williams Air Force Base, Arizona

This paper summarizes recent research at the Aircrew Training Research Division of the Armstrong Laboratory that is attempting to enhance air combat training through the development of performance diagnosis capabilities. Three systems are described: the Observing System for Critique, Advice, and Review (OSCAR), a system which provides performance diagnosis capabilities for air intercept training; the Air Combat Maneuvering Performance Measurement System (ACM PMS), a system that provides real-time measures of positional advantage and energy management for air combat engagements flown in either a simulation or range environment; and the Intelligent System for Air-to-Air Combat (ISAAC) which provides diagnostic feedback capabilities for air combat maneuvering engagements.

BACKGROUND AND RATIONALE

Over the years the value of feedback as an aid to learning and practice has been well established. In fact, the finding that knowledge of results leads to improved performance is perhaps the most solidly established of all the principles of learning. However, the degree of information provided by feedback in most real world settings can vary dramatically. Air combat training is certainly no exception and can be characterized by the development of a variety of tools to enhance the feedback provided in both simulated and real world engagements. For example, gun camera film has been now replaced with video tape that can provide both heads-up display and radar information. Instrumented ranges enable the accurate positioning of aircraft in three-dimensional space, thus permitting a graphic reconstruction of the "big picture" on an air engagement. It seems to be fairly well-accepted that the provision of such engagement feedback is of benefit to training for air combat.

Despite the apparent value of such capabilities, they provide only a reconstruction of the events that occurred within a mission. In other words, such systems provide a very good reconstruction of what happened, but leave the diagnosis of why such events may have occurred to the instructor or observer. Within air combat, the concern for training is not so much the final outcome, but more importantly, an understanding of what aircrew actions led to that outcome. For that reason, research aimed at the development of performance diagnosis capabilities for air combat training was initiated for two domains, beyond visual range (BVR) air intercept training, and within visual range (WVR) air combat maneuvering (ACM). At present, three systems have been developed and evaluated in the lab. A brief description of these three systems is presented below.

OBSERVING SYSTEM FOR CRITIQUE, ADVICE, AND REVIEW (OSCAR)

In 1988, a contract was awarded for the development of an expert system enabling performance diagnosis for basic air intercept training. This effort was one of four contracts aimed at the application of artificial intelligence (AI) techniques (expert systems and artificial neural networks) to various facets of air combat training. The goal of this effort was to develop a system, OSCAR, which could provide expert critique of performance as training feedback. Once developed, an attempt was made to determine whether such diagnostic capabilities had utility as an adjunct to basic intercept training. Only a very brief synopsis of this research will be presented here. A complete description of the effort can be found in Obermayer (1991).

An overview of the system and a brief description of its capabilities are shown in Figure 1. As shown OSCAR takes discrete, time-sample data from either a floppy disc or direct ethernet interface from the host system. For this program, the Air Intercept Trainer (AIT) which provides basic training for either the F16A or F16C aircraft was used as the host. Such raw data are reduced into a file of maneuver events and measurements which could be noted by an expert observer. Using such data, a rule-based expert system is then applied which draws inferences about performance, risk assessment, and probable causes, and also indicates alternative courses of action. For this evaluation, these inferences were based upon the "textbook solution" as found within current tactics manuals. These inferences are then integrated with a dynamic replay of the intercept, so that the student has information not only on the actual events that occurred during an intercept, but also a critique of those events and a statement of likely behaviors that lead to such observables.

A limited evaluation of OSCAR was conducted using a sample of 11 instructor pilots at Luke AFB, Arizona. The evaluation data were primarily subjective responses to a set questions dealing with the perceived value of OSCAR's instructional capabilities. Overall, the results were encouraging indicating that OSCAR was easy to use, and would have a significant training benefit, especially for individual student practice and self-debrief. Such data suggested that such performance diagnosis capabilities could have significant value for both simulation and range-based systems.

AIR COMBAT MANEUVERING PERFORMANCE MEASUREMENT SYSTEM (ACM PMS)

The ACM PMS is a state of the art graphics based workstation designed to "plug in" to several major aircrew training systems to support both operational training and training research. The system collects data in digital and audio form and provides graphic reconstruction of ACM engagements as well as a variety of objective performance measures. There are currently three operational ACM PMS systems, two of these are installed at Luke AFB, and one at Williams AFB. Of the two systems at Luke AFB, one is interfaced with the Simulator for Air-to-Air Combat (SAAC) and the other with the Air Combat Maneuvering Instrumentation (ACMI) range The ACM PMS system installed at Williams AFB is a stand alone system which is capable of replaying engagements recorded on either of the two systems located at Luke AFB. The ACM PMS system provides the following general capabilities for the SAAC simulator and the ACMI range: (1) on-line, real-time data sampling during ACM engagements; (2) on-line, real time processing of sampled data with presentation of selected data via CRT display for immediate feedback; (3) off-line presentation at a DEBRIEF station any time after the engagement of the same data as above together with cumulative statistical data for post-mission debrief and research analysis.

Each ACM PMS consists of a main computer suite, a display system and ancillary supporting computer equipment. At present, the display system uses Silicon Graphics Iris equipment, and the computational system makes use of Gould Concept Series minicomputers. A common interface between each system is accomplished through the use of nine track magnetic tape. This allows the transfer of stored SAAC and ACMI engagements to be replayed and analyzed on the various ACM PMS systems. The system is currently being re-hosted onto a Silicon Graphics Personal Iris workstation, which will dramatically reduce the footprint of the system and associated maintenance costs.

As stated above, the ACM PMS acquires sampled data in both digital and audio form from the SAAC and ACMI. This data is available to the user in several forms. A graphic reconstruction of an engagement with the accompanying engagement audio is presented through the graphic display system. This graphic reconstruction is available in both real time and for post mission review. In addition, engagement and aircraft parameters in alpha numeric form are available through the database management system associated with the ACM PMS for post mission review and analysis.

OSCAR
OBSERVING SYSTEM FOR CRITIQUE, ADVICE AND REVIEW
FOR AIR INTERCEPT TRAINING

(10NM) (20NM) (40NM) (80NM) (160NM)   (Pause) (Slow) (Normal) (Fast)   Exercise name: DEMO   (New) (Reset) (Quit)

11899 38101   SpotLight STT

| | Ownship | | 0 | 11 | 22 | 34 | 45 |
Heading 81.43
Airspeed 546.04
Altitude 14865.70
G's 1.25

Target (1)
Heading 180.0
Airspeed 528.78
Altitude 20000.00
Range 4.50
Los -1.57
AA 0.00
Score 1 0.98
Score 2 0.98

Target (1)
Heading 180.0
Airspeed 528.78
Altitude 20000.00
Range 3.35
Los -6.06
AA 0.00
Score 1 0.93
Score 2 0.93

Critique:

1 Radar setup was normal

2 Didn't ADJUST SPEED fully

3 Attacked correct TARGET first

4 Shot #1 Score1 = 0, 2 = 0 Delay .75 1 = 0 2 = 0

Further Explanation:

The shot score is a function of the Antenna Train Angle, Range, and Aspect Angle. The Result is a rule-of-thumb probability of kill at the time of the shot. The delay score is the amount of time earlier that a .75 score could have been achieved.

Rules

if
1) Nautical miles of radar gate, and
2) +/- degrees of radar azimuth scan, and
3) Number of bars of radar elevation scan,

then it is definite (100%) that Use GCI, situational awareness or briefing to point in the right direction and set radar at the driefed range, elevation, sweep, and scan.

Time [133]   0   205

(S)   (20NM) (15NM) (10NM) (#1) (5NM)   (#2) (#3) (E)

SUN 386i COLOR GRAPHICS   DEBRIEFING DISPLAY

COLLECT DATA → NARRATE → CRITIQUE

HOW OSCAR WORKS

TIME-SAMPLED AND DISCRETE DATE ARE COLLECTED VIA FLOPPY DISK OR DIRECT CONNECTION

A SMART WINDOW-BASED ASSESSMENT AND MEASUREMENT INTERFACE (SWAMI) CREATES A FILE OF MANEUVERS EVENTS AND MEASUREMENTS WHICH WOULD BE NOTED BY AN EXPERT OBSERVER

A RULE-BASED EXPERT SYSTEM MAKES INFERENCES ABOUT PERFORMANCE, RISK ASSESSMENT, PROBABLE CAUSES, AND ALTERNATIVE COURSES OF ACTION

PLAYBACK FEATURES
o CONTINUOUS PLAYBACK WITH START/STOP SET BY TIME OR NARRATION EVENT
o WHAT, HOW, AND WHY EVENTS HAPPENED, PLUS ALT. COURSES OF ACTION
o MULTIPLE GRAPHIC VIEWS: B-SCOPE, TOP/SIDE VIEWS WITH VISIBLE RADAR BEAM
o AUTOMATIC CRITIQUE AS PLAYBACK PROCEEDS, PLUS HOW CRITIQUE FORMED
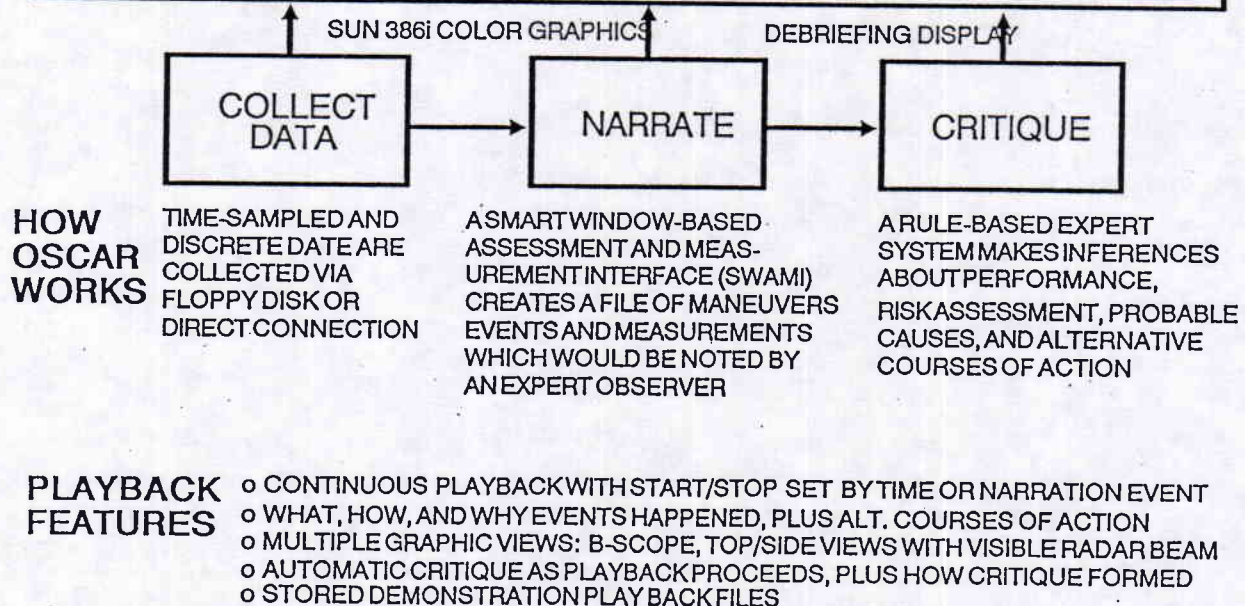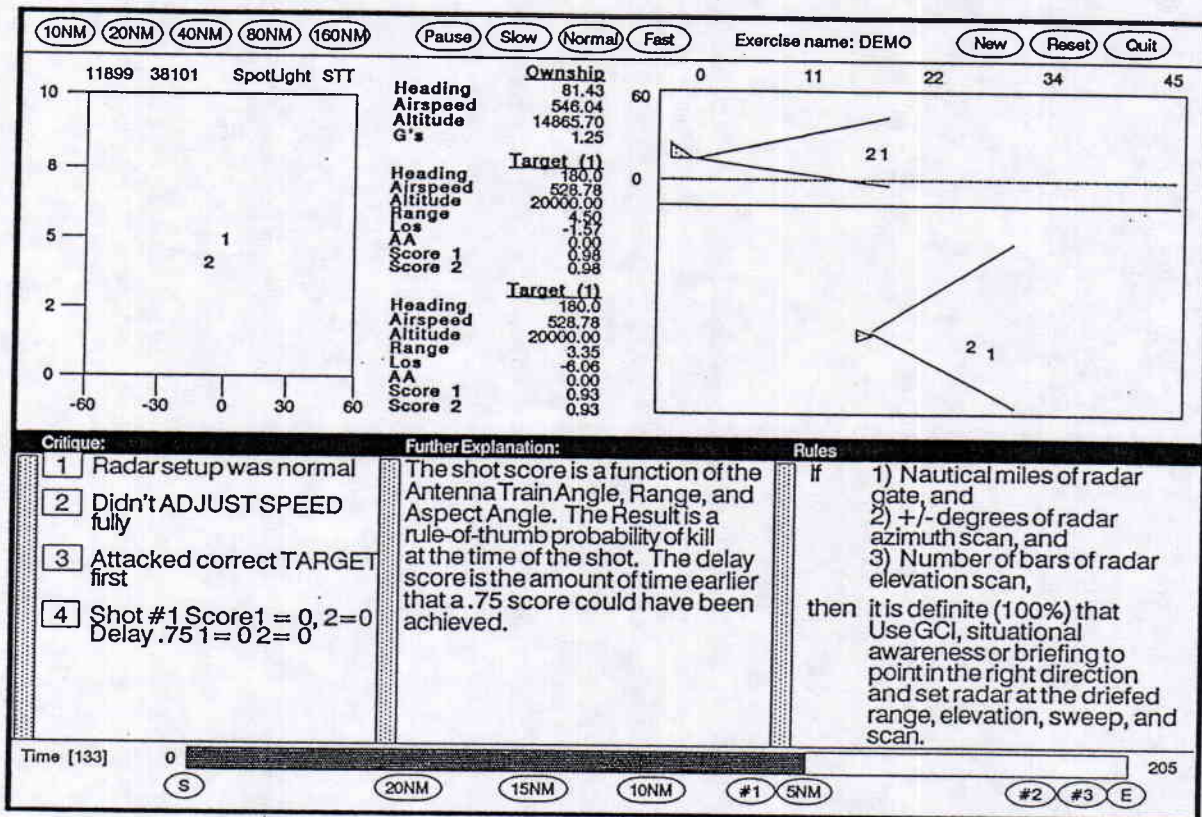o STORED DEMONSTRATION PLAY BACK FILES

Figure 1. OSCAR System Overview and Capabilities

ACM PMS DISPLAYS

The graphic reconstruction of an engagement includes five different displays. They are; Out of Cockpit, 3 Dimensional (God's-eye) view, All Aspect Maneuvering Index (AAMI) and Specific Excess Energy (P_s) time history curves, Relative Offensive Maneuvering Performance (ROMP) time history curve and the Energy Management display.

The out of cockpit view, which can be seen in either the upper right or upper left of Figure 2, provides a computer generated view of the engagement as seen through the windscreen of the selected aircraft. This view covers $\pm$ 60° in azimuth and -10° to +60° in elevation. The out of cockpit view includes some aircraft specific Heads Up Display (HUD) like information such as the airspeed scale on the left and the altitude scale on the right. The out of cockpit display also provides information relative to the selected pair (2 Vs 1 bottom center of the display) in terms of Angle Off the Tail, Slant Range, Antenna Train Angle and Closing Velocity. The Out of Cockpit Display also identifies when the aircraft achieves a radar lock on.

The God's-eye display, which is shown in the center of Figure 2, provides a three dimensional view of the engagement. The viewing angle, azimuth and elevation, and the distance from the engagement may be manipulated via the mouse. Time history trails of aircraft flight path are also available on the God's-eye display. The length of these trails is adjustable or can be eliminated all together. The God's-eye display also contains an "altitude pole" which displays the current altitude of the various aircraft.

The AAMI/Ps time history curves, which is enlarged in the center of Figure 3, provide a graphic representation of the AAMI algorithm (top half of the display) for a selected aircraft pair i.e. 1 Vs 2, and a graphic representation of the selected aircraft's energy (bottom half of the display) over the length of the engagement. The actual display is in color and AAMI curves are computed for each of the available weapons and are displayed simultaneously in color coded by weapon type. This display also includes a shot history (top of the display) for the selected aircraft. A more detailed discussion of how the AAMI is developed is provided in the Performance Measures section below.

The ROMP curve, which is enlarged in the center of Figure 4, is a graphic representation of the Relative Offensive Maneuvering Performance of a selected pair of aircraft. This curve is generated by subtracting the AAMI of the second aircraft selected from the AAMI of the first i.e. Aircraft #1 minus Aircraft #2 as in Fig. 4, with the first aircraft selected (A/C #1) displayed on the top. This curve shows very plainly which aircraft had the advantage at various times throughout the engagement. A more detailed discussion of the ROMP is provided in the Performance Measures section below.

The Energy Management display, which is shown in the upper right part of Figure 5 and also called the "Energy Doghouse", is a graphic depiction of the energy states of a selected pair of aircraft. The exterior perimeter of the "doghouse" is the flight envelope of a given aircraft, color coded to match the A/C number. The position of the A/C number located inside the doghouse represents the current energy state of that aircraft. The line which nearly bisects the interior of the doghouse horizontally represents the zero P_s state of the aircraft. Flight on the line represents sustained performance. Flight above the line indicates instantaneous performance or energy deficit while flight below the line indicates excess energy. A more detailed discussion of Energy Management is provided in the performance measures section below.
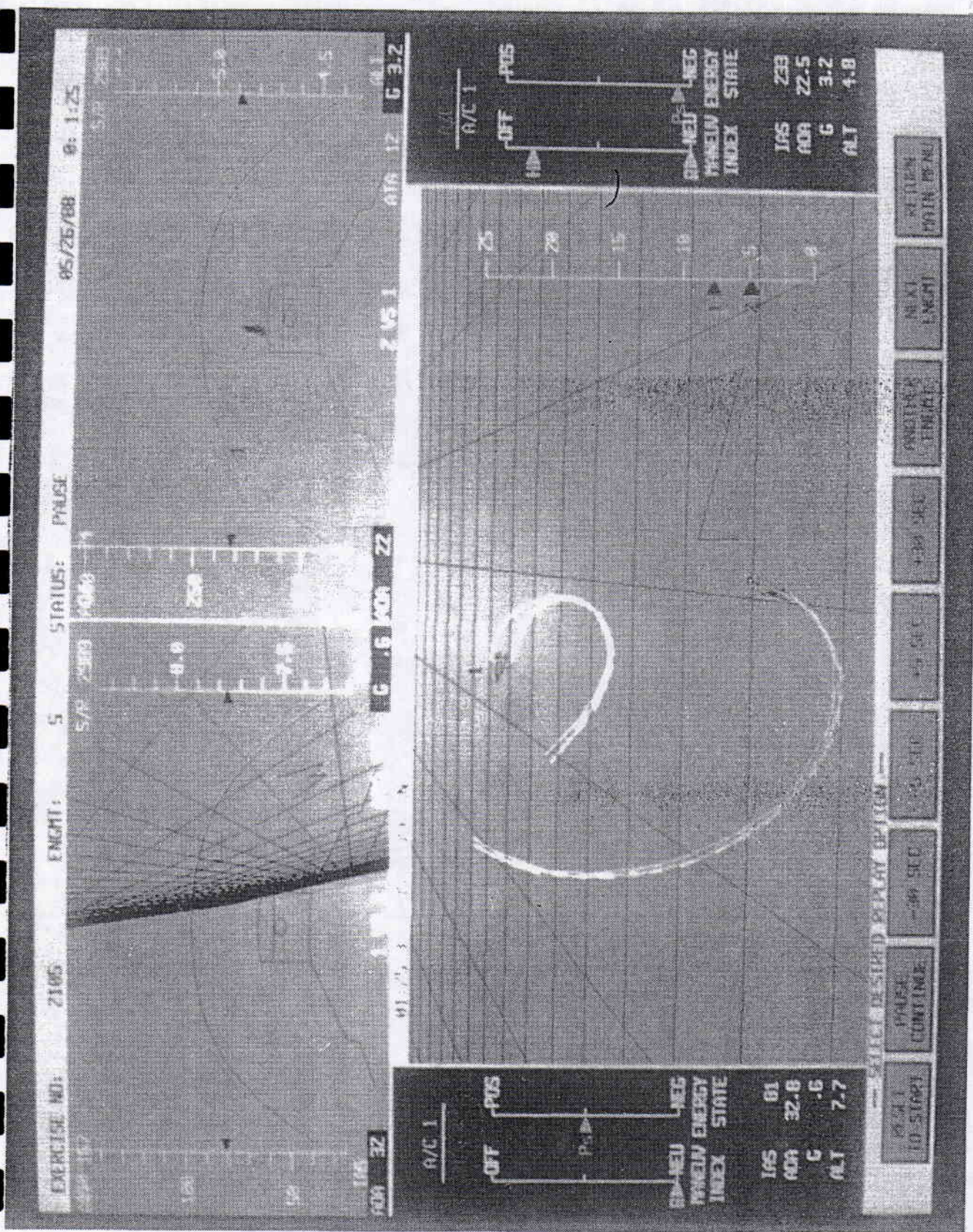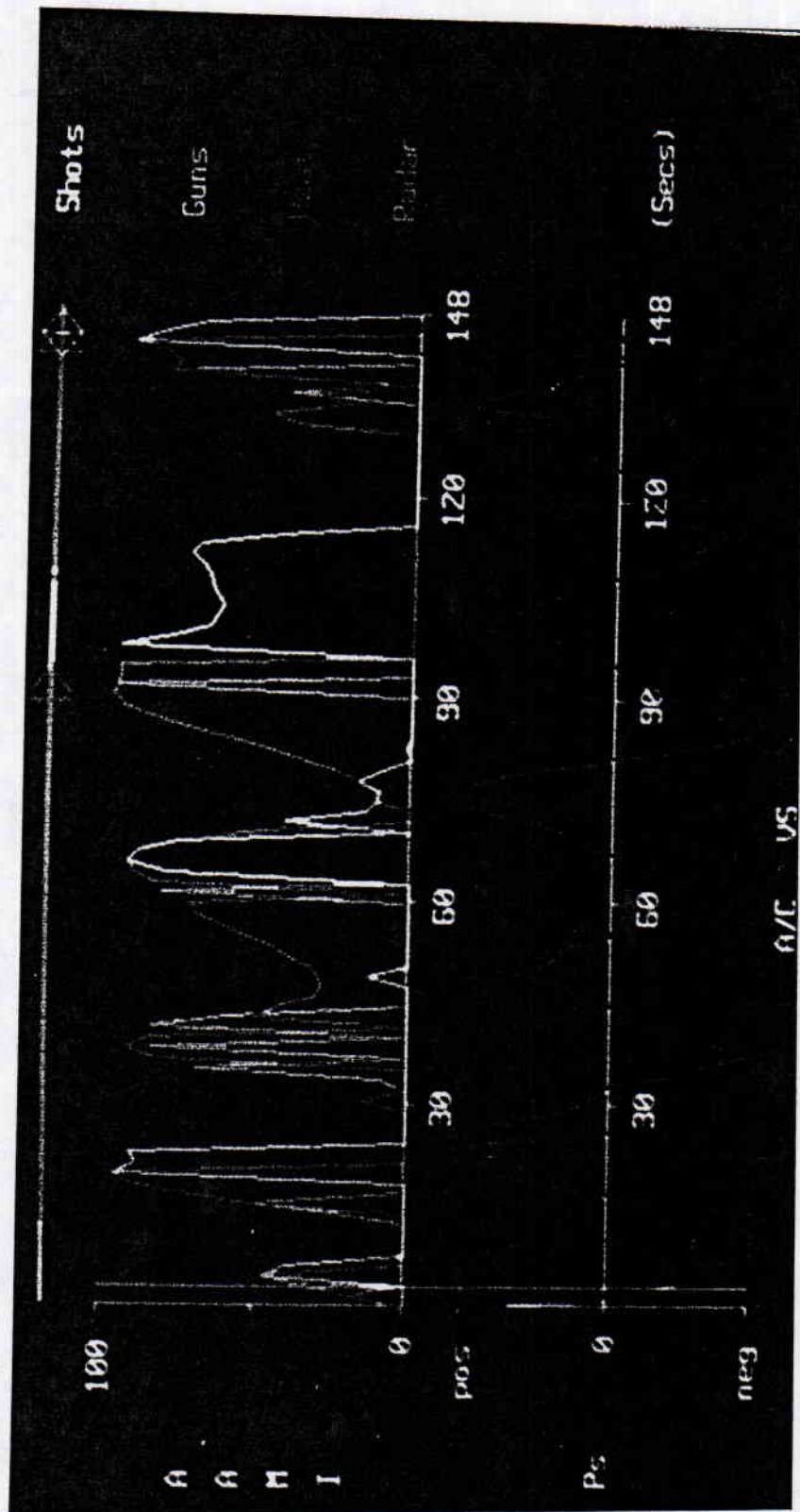
Figure 2. ACM PMS Display Example

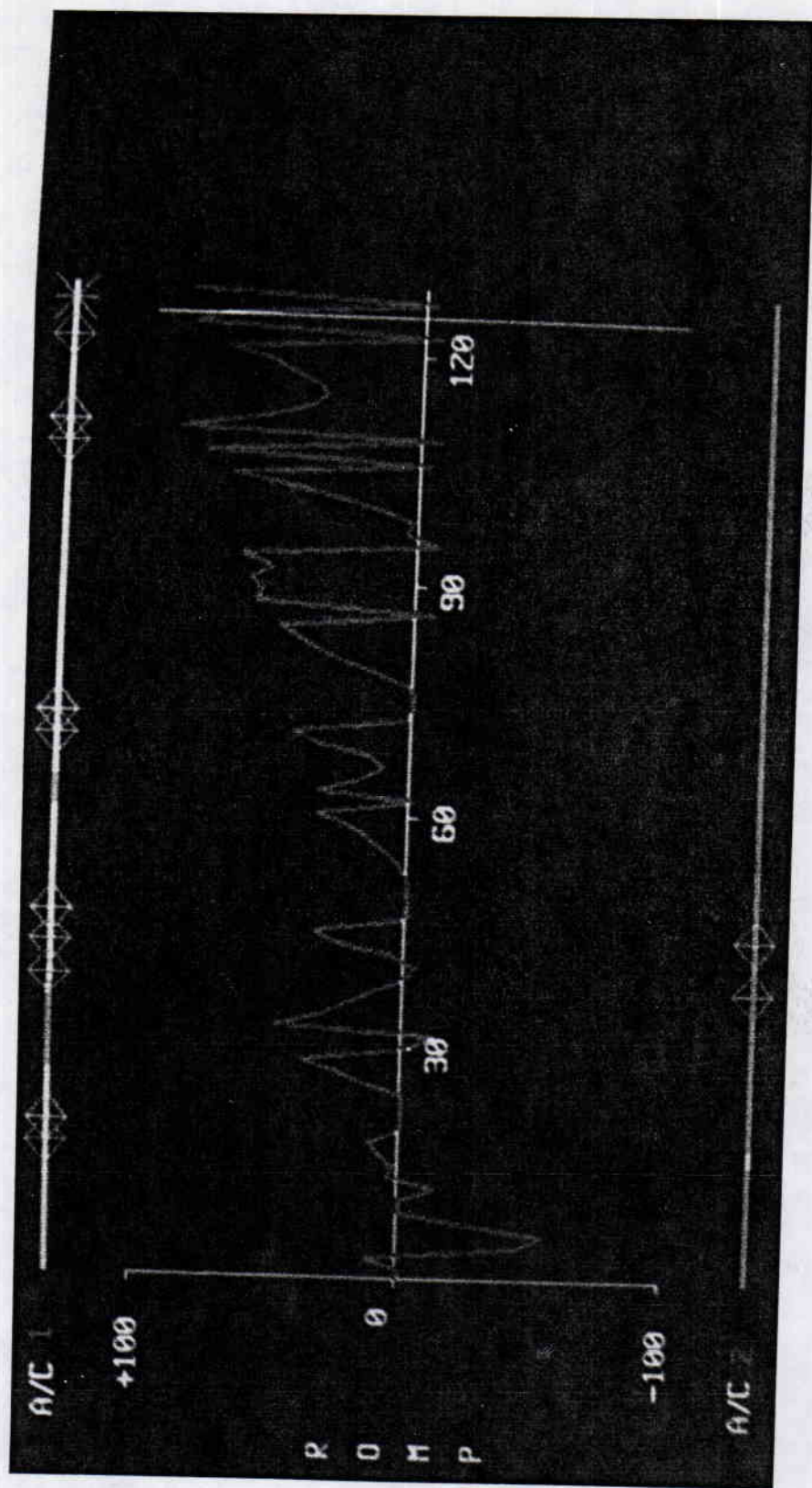Figure 3. AAMI and P_s Curve Examples
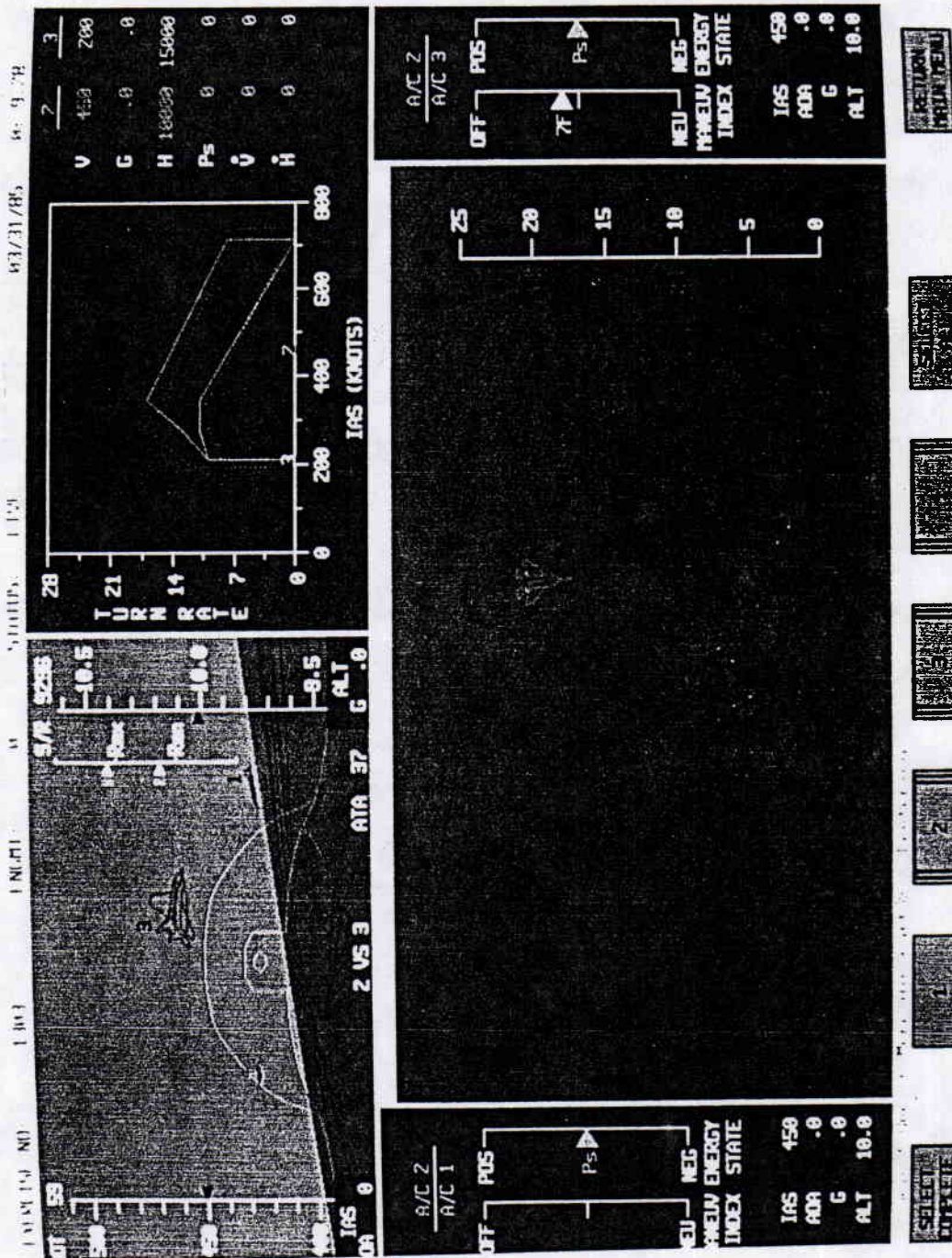
Figure 4. ROMP Curve Example

29

Figure 5. Energy Doghouse Display Example

These displays are presented on a 11 inch by 14 inch color monitor which is divided into six display windows. These windows are upper right, upper left, center, right and left side windows, and a menu area. Three of the windows, upper left, upper right and center are considered primary and can be configured with any of five displays described above. Figure 2 shows the ACM PMS display in one of the "normal" configurations, i.e., Out of Cockpit #1 upper left, Out of Cockpit #2 upper right and God's-eye center. These six display windows include eight functional areas (A - H) as described below.

Area	Area Name	Area Description
A	Upper Left Display	This is a 7" X 4" area which depending on menu selections displays: Out of Cockpit, God's-eye, AAMI & EM Time History Curves, and ROMP.
B	Upper Right Display	This is a 7" X 4" area which depending on menu selections displays: Out of Cockpit, God's-eye, AAMI & EM Time History Curves, and ROMP.
C	Center Display	This is a 10" X 5.9" area which depending on menu selections displays: Out of Cockpit, God's-eye, AAMI & EM Time History Curves, and ROMP.
D	Left Side Window	This is a 2" X 5.9" area which displays Maneuvering Index and Energy State Scales, Radar Lock information and specified A/C parameters.
E	Right Side Window	This is a 2" X 5.9" area which displays Maneuvering Index and Energy State Scales, Radar Lock information and specified A/C parameters.
F	Menus	This is a 14" X 0.8" area which displays the Menu Buttons, used to select, modify, and control the screen.
G	Message Area	This is an 8" X 0.3" area located above the Center Display area (C) which displays text formatted event messages such as Shots fired and Radar Locks.
H	Status Line	This is a 14" X 0.3" area at the top of the display reserved for status information: Exercise Number, Engagement number, Run Status (Pause, Slow Forward etc.), date and Elapsed time.

Primary control of the ACM PMS is by means of a menu system which is displayed on the very bottom of the ACM PMS screen (See Area F Fig 2). Access to these menu functions is provided through a touch screen. As mentioned previously, control of the viewing angle and perspective of the God's-eye display is provided by the mouse.

ACM PMS PERFORMANCE MEASURES

Included in the ACM PMS are several measures designed to assess ACM performance. These are the All Aspect Maneuvering Index (AAMI), the Relative Offensive Maneuvering Performance (ROMP) and the Energy Maneuverability assessment. Detailed descriptions of these measures may be found in McGuinness, Forbes, and Rhoads (1984). Validation data for these measures can be found in Waag, Raspotnik, and Leeds (1992).

All Aspect Maneuvering Index

The AAMI provides a measure of the "effective" proximity or positional advantage of a fighter relative to an adversary aircraft. This effective proximity is defined for each weapon available in the fighter's arsenal at any specified moment. AAMI values range from zero to 100, where zero indicates no offensive position and a score of 100 indicates an optimal offensive position. The AAMI is based on three parameters describing the inter-aircraft geometry: Antenna-train-angle (ATA), angle-off-tail (AOT) and range which are defined as described below:

ATA is the angle between the longitudinal axis of the fighter aircraft and the radial from the fighter's nose to the adversary. ATA is also known as the Line of Sight Angle and is expressed in degrees from zero to 180 where ATA = 0 "on the nose" and ATA = 180 when the opponent is directly behind the fighter.

AOT is the fighter's position with respect to the tail of the adversary aircraft. AOT is also expressed in degrees from zero to 180 where AOT = 0 when the fighter is directly behind the opponent and AOT = 180 when the fighter is "on the nose" of the opponent.

Range is the distance from the fighter to the adversary aircraft. It is also referred to as slant range (S/R) and is measured in a straight line from the fighter to the target.

The AAMI is calculated as follows:

AAMI = F(ATA) X WRM (AOT,R)

Where:

F(ATA) is a weighting function and is expressed as

F(ATA) = 100[(90-ATA)/90]   for ATA < or = to 90°

or   F(ATA) = 0   for ATA > 90°

WRM (AOT,R):

In theory, weapon envelopes define four ranges:

R1 - Minimum aerodynamic range
R2 - Minimum range where a Pk = 1
R3 - Maximum range where a Pk = 1
R4 - Maximum aerodynamic range

Based on inter-aircraft geometry, AOT, Range, Vc and Altitude, a look up table for a particular weapon is used to determine where in the envelope the fighter is located. If the fighter is between R2 and R3 the WRM (AOT,R) function is assigned 1. If the fighter is between R1 and R2 or between R3 and R4, an interpolation is done to determine the value of WRM (AOT,R). For example, if the fighter was half way between R3 and R4, then WRM (AOT,R) would be assigned a value of 0.5. A problem, however, that has affected the accuracy of the AAMI from the beginning is that R2 and R3 do not really exist in any official sense. In the discussion of the AAMI, McGuinness, Forbes and Rhoads (1984) the "weapons range model serves to confine the AAMI to predefined 'range windows' for the respective weapons". Further "these range windows correspond roughly to the maximum, minimum, and optimum limits of the firing envelopes". Unfortunately there is no discussion of the derivation of "optimum limits". As a result the current AAMI arbitrarily uses some factor times R1 and R4 to generate R2 and R3 respectively. Although this has been shown to be very effective in identifying the proper trend of an offensive score it should in no way be taken as an absolute offensive score.

Relative Offensive Maneuvering Performance

As noted above, the AAMI reflects the offensiveness of an aircraft relative to it's selected pair. Since AAMI is an offensive measure only, when AAMI goes to zero it is impossible to determine if the aircraft is actually neutral or defensive. One way to determine when one of the participants is neutral or defensive would be to look at the AAMI of the opponent, or what is referred to as the AAMI defensive score. The ROMP in fact does this. The ROMP is a composite of the AAMI scores of two aircraft selected as a pair. It has a value of -100 to +100 and is derived by subtracting the AAMI of one aircraft from the other. For example; if the inter-aircraft geometry was such that A/C #1 had an AAMI score of 100 and A/C #2's AAMI was zero, the ROMP for #1 would be 100 while the ROMP for #2 would be -100 showing that #2 with an AAMI of zero is not neutral but actually defensive. In a situation where both aircraft had equal AAMIs, the ROMP would be zero showing that even though both had positive AAMI's the situation was actually neutral. This information is then plotted over the length of the engagement similar to the plot of the AAMI except that zero on the Y-axis is in the middle of the scale and it goes to 100 in both directions therefore graphically showing which aircraft had the positional advantage at any given time. (See Fig 4)

Energy Maneuverability

Energy Maneuverability (EM) indicates how well a pilot utilizes potential and kinetic energy in the dynamic environment of air combat maneuvering. Energy maneuverability is a valuable research tool, offering the researcher a way to quantify energy management. The time a pilot spends above, on, or below the Ps=0 line is an index of energy management, in the same way the AAMI is an index of offensiveness. Time dependent plots of the fighter and the adversary's positions, with respect to Ps=0, are an indication of how well the pilot manages energy with respect to the adversary. Examination of EM curves provide indications of trends in energy use juring engagements or during specific maneuvers. The energy management display (Fig 5) consists of a maneuvering triangle or "doghouse" defined by a set of 12 points. Sets of these points are stored for each type of aircraft at 10,000 ft. increments from Sea Level to 50,000 ft. Indicated airspeed (knots) is presented on the X-axis and turn rate (degrees/second) is on the Y-axis. Curves representing lift limit and structural limit intersect at the aircraft's corner velocity. For a given airspeed the aircraft stalls at turn rates above the lift limit and incurs possible damage at turn rates above the structural limit. The intersection of the lift limit curve and structural limit curve is known as corner velocity and represents the instantaneous quickest tightest turn possible at the given altitude.

INTELLIGENT SYSTEM FOR AIR-TO-AIR COMBAT (ISAAC)

In an attempt to further develop diagnostic measures of air combat performance and to better understand the underlying cognitive and decision-making processes required, a project was initiated to investigate pilot expertise in one-versus-one (1v1), air-to-air (A/A) combat (Thomas, Obermayer, Raspotnik, and Waag, 1992). The objective of the effort was to develop a performance model of expert pilot behavior in air combat. The model would serve as a standard for air combat performance, and actual pilot performance that deviated from that standard would serve as data for diagnostic measures of pilot performance. Several procedures were used to determine which would be most effective for future knowledge elicitation work. The knowledge base elicited by these methods was then incorporated in a descriptive model of expert air combat performance. After additional detailed information was obtained from a subject-matter-expert (SME), the knowledge base was coded in the form of a rule-based expert system.

KNOWLEDGE ELICITATION METHODOLOGY

The subject-matter-expert (SME) used in this investigation is a former F-4 pilot with combat experience. He was director of the SAAC, and responsible for its operation, maintenance, and upgrade to the current F-15 and F-16 configuration. The SME has flown more than 500 engagements in the SAAC against pilots ranging in proficiency from novice to expert.

The SME was interviewed to obtain the top level goals of air combat maneuvering, plus the subgoals and operators which allow the pilot to achieve those goals. Goals include: Place the opponent in your cone of fire while remaining outside your adversary's cone of fire. Subgoals include: Turn faster than your opponent and point your aircraft in the direction of your opponent. Operators to accomplish these goals include: Turn in the direction of the opponent, place him on the plane of the vertical stabilizer (PVS), and pull him to your nose.

The SME flew a series of 1v1 air combat engagements against an another former fighter pilot in the SAAC. Each pilot began the engagements in either an offensive, defensive, or neutral position. Immediately after simulator sessions the engagements were replayed on the ACM PMS. The SME was video taped as he debriefed his own performance during replays, describing his goals, actions to meet those goals, and the necessary conditions for initiating those actions. This information was used to confirm data collected in the interviews, to elaborate and refine the goals and operators, and to determine which operators were appropriate under what circumstances. From a methodological standpoint, this procedure appeared appropriate to meet the aforementioned objectives; however, it was noted that the SME occasionally confused air combat engagements. This was not unexpected since his behavior was similar in several engagements, and the time between engagements and debriefing those engagements usually exceeded one hour. This knowledge-elicitation procedure may be appropriate for identifying general principles of air combat and specific instances where air combat rules apply, but may not be ideal for investigating specific pilot decisions during air combat.

Two similar knowledge elicitation procedures were then used to add more air combat rules to the database. The SME was audio taped as he identified his air combat goals, his actions to achieve those goals, and the situational variables that dictated those actions. The SME again flew a number of engagements against the same former fighter pilot in the SAAC using the same initial conditions as before. In one condition, the SME described what he was doing and why, while flying in the SAAC, and in the other condition he did so immediately after flying each engagement. These methods resulted the identification of a set of situational assessment variables such as nose position, closure, energy, aspect, range, and altitude; specification of additional air combat rules; and identification of more instances where the rules apply. It was noted that performing in the SAAC occasionally

interfered with the SME's ability to describe and interpret his actions. In the other condition, where the SME debriefed after engagements, he occasionally forgot details of the air combat.

A final procedure was used to refine situational assessment variables, to elaborate and refine air combat rules, and to identify specific instances where rules apply in achieving the stated goals of air combat. The SME again flew a number of air combat engagements in the SAAC against the same former fighter pilot. In this condition, opponents did not describe their actions until the end of each engagement. Engagements were replayed in the SAAC so that opponents could see each engagement recreated to include all in-cockpit displays and out-of-cockpit visuals. There is also a freeze capability in the SAAC's replay function. This allowed the SME to freeze the replay so he could fully elaborate on what he had done and why. SME comments were again audio taped. As would be expected, this condition placed the least demands on the SME's memory, and with the absence of the competing task of flying, afforded him ample time to describe the rationale behind his air combat behaviors. This procedure will be used in the future to elicit knowledge for additional SMEs.

The information obtained from the above procedures was compiled and modeled, and then provided to the SME for critique and review. He provided additional detail to existing rules and additional air combat rules that were not derived using the previously described methodologies. The final set of rules were then prepared for inclusion in a rule-based production system.

PRODUCTION SYSTEM DEVELOPMENT

The purpose of production system development was to provide a model of expert performance in F-15 and F-16 air combat. A requirement of the expert system was that it be capable of interfacing with the SAAC database which includes 500 engagements between our SME and 125 pilots. The expert system was to include a performance measurement and critiquing capability, and be easily validated using SAAC engagement data. Validation testing would include determining if the SME actually followed his own rules, and if the model could predict air combat winners and losers, and expert and novice pilots.

The initial expert model described the first several "moves" appropriate for the line abreast initial condition where opponents start at co-altitude, 6000 feet apart. The appropriate things to do, according to the SME, are to turn in the direction of the adversary until the opponent aircraft appears on the plane of the vertical stabilizer (PVS) (a plane that extends from the nose to the tail of an aircraft), and then pull hard on the stick, so as to point the aircraft at the adversary. Assuming both opponents do the same thing (if one does not, he will be at a significant disadvantage), the line abreast condition will convert to a near head-on condition. If one of the opponents achieves a significant aspect angle advantage as a result of making a smaller initial turn, that pilot should reverse the bank of his aircraft to maintain visual contact with the other aircraft. He should then begin a lead turn before the airplanes pass head-on. This set of actions will give the lead-turning aircraft an additional aspect angle advantage on the next head-on pass.

The above example was coded using the expert system shell, PCPlus. This shell requires production rules that define appropriate aircraft maneuvers, additional rules to define these maneuver rules in terms of aircraft state parameter data, rules to search the database to determine if state parameters requirements have been satisfied, and rules that report if aircraft maneuvers have been performed correctly. The resulting expert model is; Therefore, a hierarchy of rules and specifications to include goals, top-level rules, translation rules, parameter definitions, special default provisions, and software to process engagement data. The expert system is primarily a backward chaining inference system, that proceeds backward from specified goals, chaining through the applicable rules, to determine if the goal was satisfied. Examples of goals include: a maneuver goal, to test if pilot

maneuvering conforms to the SME rules, and goal reporting, to ensure that output required for future analyses is recorded.

Top-level rules infer a yes/no value for each of the goals. MAN 1 and MAN 2 rules are each defined in terms of more than one specific pilot action, as described by the SME. These rules determine if Maneuver 1 and Maneuver 2 were performed correctly.

RULE 11
> Subject: Maneuver 1 Rules
> If : (Roll_Toward_Bogey_Man1 And Bogey_On PVS_Man1 And Max
> _G_Man1)
> Then: (Turned_Into_Bogey)

Top-level rules use terms which require further definition to determine values in terms of available engagement data. For example, statements such as "roll toward the bogey" and "on the PVS" require <u>translation rules</u> that specify the behavior that defines the top-level rules. Defining these translation rules often required additional interaction with the SME, since the content of these rules is only implied by top-level rules.

RULE 23
> Subject: Translate-To-Data-Man1-Rules
> If : ((Left_Abreast And Aroll_F_2 < 0 And Aroll_F_4 < 0)
> or (Right_Abreast And Aroll_F_2 > 0 And Aroll_F_4 > 0))
> Then: (Roll_Toward_Bogey_Man1)

A third level of the expert system is parameter definitions. The parameters are used by the translation rules and must be defined for the expert system. Parameters are defined by such values as number, positive number, string, and single- or multi-valued. Parameters also identify data from the air combat engagement file by file name and location in the file.

AROLL_F_2
> Translation: (Roll Angle, A/C 1, 1/4 Betw Start And CPA1)
> Type: Singlevalued
> Used By: (Rule023)
> Method: (Dos-File-In PCFILE.11 Index 58)

Due to the idiosyncrasies of PCEasy, some additional information must be provided by giving specific values to parameters. This "special case" is an output message parameter where a value is the message. If a yes value for a yes/no parameter or goal cannot be established, PCEasy will infer "don't know"; or if unable to establish a "yes" value should result in a "no" value, then the parameter must be given a "no" default value.

MAN1
> Translation: (Maneuver Segment 1 Appropriate?)
> Type: Yes/No
> Updated-By: (Rule010 Rule055)
> Used-By: (Rule033 Rule042 Rule009)
> Default: (No)

Software was developed to process air combat engagements for use by the expert system. A "C" program was developed to process SAAC engagement files into a form suitable for the expert system. This program encodes engagement file data in the format required by PCEasy; parses time history files into segments corresponding to commonly occurring events such as start, first merge, second merge, and various typical aircraft maneuvers; and provides computations for variables such as "on the PVS", "bogey in view", "percent of time in cone of fire", and percent of time offensive, defensive, or neutral.

Subsequent work involved adding air combat rules to the existing knowledge base, and refining and testing those rules, and partitioning the knowledge base into frames corresponding to commonly occurring segments of air combat. The first frame includes rules describing initial conditions, rules required to bring the adversaries to the first merge, and rules that apply at and immediately following the merge. Since air combat often involves a series of near head-on passes, the second frame includes rules that describe a series head-on passes. Frames were also developed to include rules that indicate what the pilot should do when he is either offensive or defensive with respect to the adversary. A final frame was developed to include rules that apply when neither pilot is offensive and both aircraft are in close proximity.

Model validation is currently underway and will determine the degree to which the performance of the model compares to that of actual pilots. For example, can the model predict winner versus loser and novice versus expert performance, and does the model compare favorably to air combat rules specified by other SMEs?

FUTURE PLANS

At present, ISAAC is currently under evaluation to determine the validity of its rule-base. The initial attempt is to determine whether the rules that have been developed describe the actual behavior of the subject-matter-expert during simulated air combat engagements. Once the validity has been established, ISAAC shall be integrated with the ACM PMS to permit a comprehensive replay and performance diagnosis debriefing capability. The integrated system shall be evaluated within the context of air combat training using the Simulator for Air-to-Air Combat (SAAC). In the event such capabilities are considered to be of value, the next phase of the program would entail the development of such diagnostic capabilities for the multi-ship air combat arena. Efforts would focus on both the BVR and WVR aspects of air combat.

REFERENCES

McGuiness, J., Forbes, J.M., & Rhoads, J.E. (1984). Air combat maneuvering performance measurement system design. (AFHRL-TP-83-56, B081060L). Williams AFB, AZ: Air Force Human Resources Laboratory, Operations Training Division.

Obermayer, R.W. (1991). Observing system for critique, advice, and review (OSCAR). (AL-TR-1991-0059). Williams AFB, AZ: Armstrong Laboratory.

Thomas, G.S., Obermayer, R.W., Raspotnik, W.B., and Waag, W.L. (1992). Modeling pilot expertise in air combat. To be presented at Annual Human Factors Society Meeting, Atlanta, GA.

Waag, W.L., Raspotnik, W.B., & Leeds, J.L. (1992). Development of a composite measure for predicting engagement outcome during air combat maneuvering (ACM). (AL-TR-1992-0002). Williams AFB, AZ: Armstrong Laboratory.